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1949

INSTRUCTION MANUAL

for use with the

"TTR"

TRANSFORMER TURN RATIO TEST SET

JAMES G. BIDDLE CO.

ELECTRICAL & SCIENTIFIC INSTRUMENTS

1316 ARCH STREET · PHILADELPHIA 7, PA.

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First Edition
MARCH, 1949

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FOREWORD

The "TTR" Transformer Turn Ratio Test Set is a new instrument that meets a long-felt need for a portable, direct-reading, and simple-to-use device for measuring turn ratio and for indicating polarity in transformers. It is designed particularly for use on power and distribution transformers.

* * * * * *

These instructions for using the "TTR" Set are written to aid you in obtaining maximum usefullness from ratio measurements. Hence, much of the material pertains to interpretation of results and discussion of transformer and characteristics. Manipulation of the set itself is simple, as explained on the instruction card mounted in the instrument cover.

* * * * * *

To realize the full advantages of the "TTR" Set it should be considered as a new tool for investigating transformer troubles, as well as a means for checking specification ratios. By virtue of its ability to make precise ratio measurements easily and directly, it provides information that is essential for the solution of transformer problems, both in production and in the field. Such data supplement the user's knowledge of and experience with transformers.

It is suggested that those using the "TTR" Set for the first time familiarize themselves with the instrument by making a few exploratory measurements on a simple transformer in good condition. Take, for example, an ordinary distribution transformer, preferably one rated 115 x 230 volts, arranged for 2-wire connections and having HV taps. By measuring the ratio of each available HV winding, first to the LV series connection and then to the LV multiple connection, one will become familiar with the essentials of operating the set. It is desirable also to make artificial faults on an otherwise good winding, such as by adding or subtracting turns and then proceeding to identify them.

* * * * * *

Since the "TTR" Set is a new development we invite your criticism of the instrument and of these instructions. We desire especially to hear from you if you have any difficulty.

Although a number of "TTR" Sets are already in use, and helpful experience has been gained with them, we are certain that new and valuable experiences will be had as time goes on. This will provide additional "know-how" which should be shared throughout the industry.

JAMES G. BIDDLE CO.
Philadelphia
March 1, 1949

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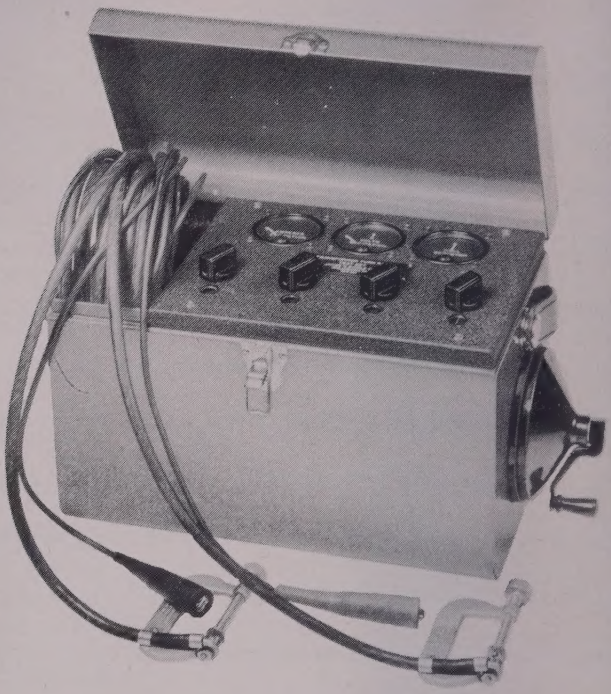


FIGURE 1. Showing the TTR Set with leads and carrying strap - an entirely self contained test set.

Section I

DESCRIPTION

The Transformer Turn Ratio Test Set has been developed to measure the turn ratio of power and distribution transformers and other conventional types (including autotransformers) having rated or nameplate voltage ratios which are the same as the nominal turn ratios.

Direct-reading tests of turn ratio (as distinguished from voltage ratio under burden) are made with a high degree of precision by means of a single, portable, self-sufficient equipment applicable to any ratio or size of transformer commonly occurring in power systems. The measurement is independent of the regulation characteristics of the transformer under test.

An important, although indirect, use is to identify sources of trouble in transformers. Incorrect taps, errors in turn count, and mislabeled terminals can be detected by comparison to measured turn ratios. Shorted turns, interconnections between windings, and other defects may be detected before the transformer is placed in service. Errors or failures in tap-changers also affect the apparent ratio.

The TTR Set is not designed for use on instrument transformers or other types which are compensated nor transformers which have voltage ratings so low that saturation occurs at the level of the test nor those which require exciting current in excess of that which can be supplied by the set. Current transformers, furnace transformers, welding transformers, and large rotary converter transformers are likely to require excessive exciting current. The TTR Set is not designed for accurate measurement of ratios on those special types of transformers having high reactance produced by mag-

netic shunts disposed between exciting and secondary windings. Construction of this sort shunts part of the magnetic flux around the secondaries and does not satisfy the principle that induced potentials are proportional to turns. Some rotary converter transformers and transformers used with gaseous discharge lamps are examples of this type.

Altho a fault on the transformer under test may produce a load or otherwise affect ratio and so be detected during ratio tests, the TTR Set does not test insulation.

The TTR Set is essentially a reference transformer with which all necessary facilities for a field test of ratio by "back-to-back" null balance are combined in a portable unit.

The reference transformer is specially constructed to have characteristics which appropriately match those of power and distribution transformers under the conditions of the ratio test. It is tapped in decades and its exact turn ratio is selected by adjusting the first three dial-knobs on the instrument panel. The exciting winding is wound with sufficient copper to minimize potential drop and is distributed on the core to reduce flux leakage. High permeability core alloy ("Hipernik")* is used to reduce exciting current.

The decade switches select the taps of the reference transformer. Any ratio in the range between 0.1 and 129.9 may be selected. The first dial selects steps of 10 from 0 to 120. Steps of 1.0 from 0 to 9 are on the second dial. Steps of 0.1 from 0.0 to 0.9 are on the third dial. These are the absolute turn ratios of the reference transformer and therefore are the turn ratios of the respective transformers under test when balance is obtained. The ratios are expressed decimally.

The fourth dial operates a continuously adjustable linear potential dividing resistor, energized from a special auxiliary circuit. It divides the smallest turn ratio increment of the reference transformer into 100 parts with sufficient overtravel to permit obtaining definite balance at 0.000 and at 0.100 graduations. Altho

* T. M. of Westinghouse Electric Corp.

interpolation is usually unnecessary, the dividing resistor is wound with sufficient turns to permit estimating to one-quarter division. The indication on the fourth dial is additive to that of the other dials. No negative increment is included in the graduations. The index mark is coplanar with the graduated dial to avoid parallax errors. Rotation may be either forward or backward and is continuous thru the arc marked OPEN between high and low ends. While the fourth dial is open (also between steps on the three dial switches) the secondary (H1, H2) circuit is open.

The galvanometer is a zero center, 200-0-200 microampere d-c movement connected to a synchronous commutator on the generator shaft. This combination in series with the differential potential between secondaries of the transformers is sensitive to the in-phase component of circulating current. A surge protector limits the potential across the galvanometer so that operation at extreme unbalance will not damage the galvanometer. It is the most sensitive available galvanometer having sufficiently sturdy construction for this application. In combination with the synchronous commutator on the generator shaft the galvanometer indicates not only the unbalance but also the sense (direction) of unbalance. The circuit is so polarized that change in galvanometer deflection follows the rotation of the dial-knobs. Hence, to move the pointer clockwise the dial-knobs are turned clockwise. Galvanometer sensitivity is matched to the ratio increments so that at any ratio a change of 1 part per 1000 of indicated ratio (from balance) will produce a galvanometer deflection of approximately 1/16 inch. Hence, at a high ratio such as 100 the change in galvanometer deflection for a ratio change of 0.1 is about the same as that produced at a ratio of 1.0 by a 0.001 change. Actual deflection of the galvanometer is proportional to the circulating current and will vary with the impedances of the transformers tested.

The a-c hand generator supplies the energy to excite

the transformers during the test and by variation of speed may be used to control sensitivity as balance is approached.

Its maximum output current of approximately 2 amperes is adequate to excite practically all sizes and types of power and distribution transformers at the excitation level of the ratio test. Special types of transformer which require high exciting current are discussed in Section IV.

Since exciting current is essentially magnetizing current the power required is very low. Hence any burden appearing as a result of fault or of extreme ratio unbalance will be felt as a load on the generator crank. The amount of power available is limited safely by the hand crank without unduly restricting the available magnetizing current. The synchronous commutator is mounted on the shaft extension of the generator. The phase of the commutator and brushes is factory-adjusted to discriminate against the quadrature component.

The voltmeter is connected in the generator output to indicate the exciting potential and its scale has only one graduation, at 8 volts, which is the rated potential for the ratio test. The movement is of the movable iron type.

The ammeter is connected in the generator output as an indication of the relative exciting currents of the transformers to be tested. It will be apparent that the exciting current (approx. 0.03 amperes) of the reference transformer is a negligible part of the current indicated on the ammeter. Since frequency and wave-form in the exciting circuit may vary, it is undesirable to interpret the ammeter indication in ampere units. The movement is of the movable iron type calibrated for 1/2 ampere at center scale.

The exciting leads are equipped with C clamps for easy connection to the transformer under test. Excitation is supplied to the terminals of the transformer under test thru the screws of the clamps. The exciting leads of the reference transformer are energized thru

the anvils of the clamps which are specially designed to penetrate surface dirt. Note that the anvils are insulated from the supply leads. The exciting leads (X) are extra flexible heavy conductors. The supply leads (S) are #18 conductors cabled with the respective exciting leads. These cables are permanently attached to the TTR Set and are as long as possible considering convenient diameter and maximum resistance (See page 65). They may be coiled into the lead compartment for storage. The sheath is oil-resistant Neoprene.

The secondary leads are equipped with insulated clips. They are three feet longer than the exciting leads and jacketed with oil-resistant Neoprene. Since resistance is not critical they may be extended as necessary by any convenient conductor.

The case terminal is connected to the chassis and to all metal supporting parts. It is insulated from the test circuits and may, therefore, be grounded if desired. It is not necessary to ground the case under usual circumstances.

The case is fabricated of steel and aluminum. The carrying strap may be adjusted for shoulder or hand length. The feet are oil-resistant synthetic material. Brief instructions and schematic diagram are mounted in the cover which may be removed for convenience during tests.

DEFINITIONS

American Standard Terminology for

Transformers, Regulators and Reactors

(ASA C57. 10-1948)

The Ratio of a Transformer is the turn ratio of the transformer unless otherwise specified.

The Voltage Ratio of a Transformer is the ratio of the rms primary terminal voltage to the rms secondary terminal voltage, under specified conditions of load.

The Turn Ratio of a Transformer is the ratio of the number of turns in the high-voltage winding to that in the low-voltage winding.

The Primary Winding* is the winding on the input side.

The Secondary Winding* is the winding on the output side.

*The terms used throughout this manual to distinguish between "test" and "reference" transformer windings are as follows:

Exciting Winding

- refers to Primary winding of the reference transformer.

Excited Winding

- refers to a winding of the transformer under test selected to be excited for the purpose of ratio tests. This may be either primary or secondary in normal operation. It is usually the low-voltage winding.

Secondary

- refers to the winding of either test or reference transformer to which the H clips are connected. Null balance is obtained between respective secondaries. The secondary for test purposes may be either primary or secondary for test purposes may be either primary or secondary in the normal operation of the test transformer.

FIGURE 2. Definitions.

Section II

OPERATION

An instrument operates on the principle that under no burden (no load) the terminal voltage ratio of a transformer is almost exactly equal to its turn ratio. When two transformers are connected in parallel and excited, there will be circulating current between their secondaries unless the turn ratios of the two transformers are identical.

Ratios are expressed decimally referring any selected winding to another winding. The low-voltage winding of a two winding transformer is the reference winding (see Fig. 2). For turn ratio measurements the reference (LV) winding of the transformer under test is connected in parallel with the exciting winding of the TTR reference transformer; and the winding of which the ratio is to be determined is connected in opposition to a tapped winding in the reference transformer with the null detector between them. When excitation is applied by cranking the generator, the difference in potential between secondaries of the two transformers is applied to the null detector, D, Fig. 3. The first revolution of the crank is enough to observe whether the ratio setting is high or low. The detector system is so polarized that the decade dials may be turned in the same sense as would be required to bring the pointer of the galvanometer back to zero. Manipulation of the decade dials is identical with the operation of a conventional potentiometer or bridge. As balance is approached the generator is cranked steadily and increased sensitivity is obtained by increasing the speed.

Model 2

INSTRUCTIONS

Patent Applied For

1. The "TTR" Set is used for measuring turn ratio of conventional types of power and distribution transformers and autotransformers, having rated or nameplate voltage ratios the same as the actual turn ratios. Core must be normal (e. g. all iron in place).

2. Disconnect and isolate transformer under test. Remove any external burden or short-circuit. In "hot" yards, avoid magnetic or capacitive coupling. ***Observe safety precautions.***

3. Connect as shown in sketch. Make sure the X_1 and X_2 clamp connections make good contact, and that the whole of the low-voltage winding is included. (For exceptions, see Instruction Manual 55-J). ***Important:*** all connections between sections of the winding which is excited must be of low resistance, capable of carrying full rated amperes.

   The H_1 and H_2 clips may be connected to any winding (or section), the ratio of which is to be measured with respect to the excited winding.

4. The X_2 clamp and the H_2 clip (marked in red) have same instantaneous polarity. Red connections are on same side (opposite each other) in transformers having subtractive polarity and are crossed when polarity is additive.

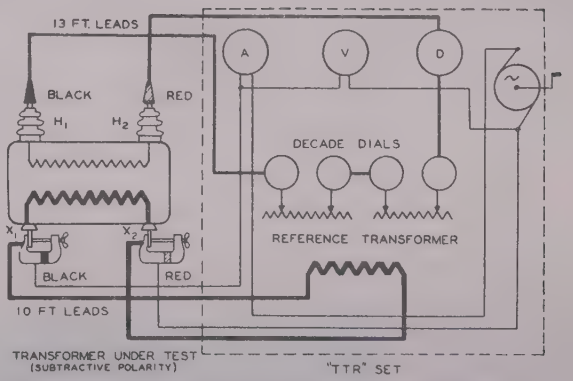
5. Set the four dial switches to zero, (i. e. 00.000). Turn the hand crank slowly 1/4 to 1/2 turn. Detector pointer should swing sharply to the ***left.*** If pointer swings to the right, connections are reversed, or transformer has reversed polarity. Keep all dial switches at zero for this test.

6. While turning crank ***slowly,*** increase ratio in first (left) dial switch till detector pointer swings to right. Turn back to highest position where pointer swung to left.

7. In same manner, increase ratio successively in second and third dials.

8. Increase ratio in fourth dial, adjusting to a null balance (center zero reading of the detector) while the speed is raised and held at approximately 8 volts excitation.

9. The turn ratio of transformer under test is then read directly from a ***summation*** of the dial switch indexes, for example 63.745. Decimal point is always between the second and third dials.



10. For testing polyphase transformers, see INSTRUCTION MANUAL 55-J.

11. ***To Check the Set.*** The Set should balance at 1 000 with clips H_1 and H_2 connected directly to clamps X and X_1 mark to mark. The Set should balance at zero with clips connected to each other and clamps left free. The clamp screws must be closed for these tests.

12. READ INSTRUCTION MANUAL 55-J and keep a copy with the Set at all times.

13. For service or repair, communicate with —

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1316 Arch Street Philadelphia 7, Pa.

Final balance is obtained when the detector galvanometer is at zero while the generator is cranked at the speed required to bring the applied potential to 8 volts as indicated by the voltmeter (See Fig. 3). The exciting potential, frequency, and current may vary somewhat according to test conditions.

The essential relationship between elements of the TTR Set is shown in Fig. 3. Note that separate conductors are used for supply leads so that the equipotential reference for excitation of the two transformers is between the clamps which connect the TTR Set to the transformer under test. Resistance introduced between the clamps and the transformer under test should be avoided by attention to contact conditions and by using no exciting leads other than those supplied with the TTR Set.

The brief instructions for connecting and operating the TTR Set (mounted in the cover of the instrument) are reproduced in Fig. 3. In the sections which follow each topic on the instruction card is discussed in greater detail.

1. The "TTR" Set is used for measuring turn ratio of conventional types of power and distribution transformers and autotransformers, having rated or nameplate voltage ratios the same as the actual turn ratios. Core must be normal (e. g. all iron in place).

The TTR Set may be used to measure the ratio of any transformer which satisfies the conditions of rational excitation set forth on Page 33 under "The Transformer Under Test". Extension of the principle to transformers having special characteristics is obviously practical. When ratio tests are made on transformers during assembly, practically all of the yoke must be stacked to obtain accurate measurement. Otherwise the magnetic circuit may be inadequate because of reduced cross section, dissymmetry, or excessive air gaps. To expedite shop work on new or rewound transformers it may be desirable to make preliminary ratio tests with the core partially stacked, making due allowance for the magnetic condition.

2. Disconnect and isolate transformer under test. Remove any external burden or short-circuit. In "hot" yards, avoid magnetic or capacitive coupling. ***Observe safety precautions.***

In order to be operative with transformers of various types, including autotransformers, and in the presence of faults, the TTR Set is so connected and so insulated that each section of the circuit is isolated from ground and from other sections (Fig. 4) except thru such connections as are established by the test. Hence, the secondary leads may be connected to any winding or section of winding including that to which excitation is applied.. Any winding of the transformer under test may be grounded. Obviously the transformer under test must be disconnected from other equipment to avoid energizing such other equipment as well as to avoid placing a burden (See Page 59) on the transformer under test.

Interference from stray electrical fields is not likely to occur at final balance. The generator may be operated slightly above or below rated test voltage in order to avoid testing at the interfering frequency, when necessary. In the vicinity of high potential lines magnetic or capacitive coupling between the equipment under test and the energized lines may occur. Such difficulties are avoided by observing practices applicable to all work in "hot" locations. (For Safety Precautions See Page 23) The requirements for rational excitation as set forth on Page 33 must be fulfilled.

3. Connect as shown in sketch. Make sure the X_1 and X_2 clamp connections make good contact, and that the whole of the low-voltage winding is included. (For exceptions, see Instruction Manual 55-J). ***Important:*** all connections between sections of the winding which is excited must be of low resistance, capable of carrying full rated amperes.

   The H_1 and H_2 clips may be connected to any winding (or section), the ratio of which is to be measured with respect to the excited winding.

Low resistance in the excited winding and its connections is necessary to avoid excessive potential drop errors. The TTR Set is designed to make accurate (See Page 26) ratio measurements on power and distribution transformers when the excited winding is one suitable for normal operation at the full-rated load of

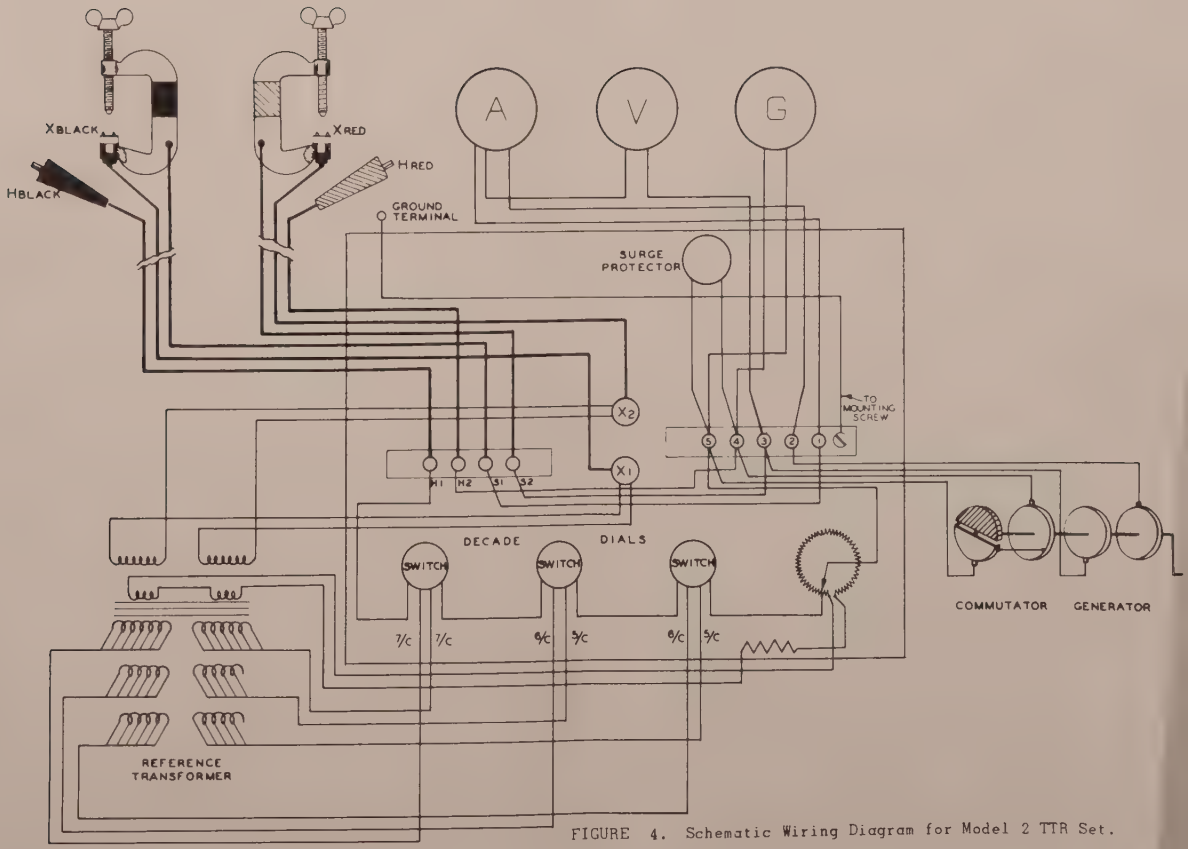


FIGURE 4. Schematic Wiring Diagram for Model 2 TTR Set.

the transformer. The resistance of such a winding is low enough, but high resistance may be introduced by poor joints or dirty contact surfaces which are in series with the excited winding.

The exciting leads of the TTR Set must also have low resistance and, therefore, only the leads supplied with the TTR Set should be used. (See Page 65)

In addition to obtaining low resistance in the excited winding, the whole of the low-voltage winding is included in order to assure distribution of the magnetizing ampere-turns over the full length of the magnetic circuit. (See Page 33) In some transformers the geometry and the resistance of the windings may be such that both magnetic and potential drop errors are negligible, in which event the difference between ratio measurements made with excitation on the whole, full-rated winding and those made with excitation on a partial winding will not be apparent, but it is usually simpler to excite the whole LV winding than to determine whether or not partial excitation will be adequate.

In a three-winding transformer the tertiary winding may not be preferable for excitation even tho its rated voltage be lower than that of either full-load winding. If the tertiary winding is rated for less than full-load kva it may have relatively high resistance which would make it less suitable for use as the excited winding than a full-rated winding would be.

Low side multiple/series connections may be excited in either connection, but all of the winding should be included. If exciting current is relatively high the series connection may be preferred since the magnetizing current will be reduced by a factor of 4 (See Page 36) as compared to the multiple connection. On the other hand, if the voltage rating be relatively high and the rated capacity low the multiple connection may be better.

On autotransformers or similar windings when it is desired to measure the ratios of various taps in terms of the whole winding, the clamps are ordinarily attached to the extreme ends; while the clips are connected to one

end and a tap, or to any two taps. The ratio will then be less than unity. For example: the ratio should be exactly 0.500 on a center-tapped winding. In cases where a tapped section of a winding is designed to operate at full transformer capacity, the clamps may be attached to this section, and the clips to the complete winding. The ratio will then be greater than unity.

Some transformers, especially those of very small size, may be tested successfully by exciting on the high side and reading the ratio as less than unity. Since the TTR Set has only three decimal places on the ratio dials, this is done at a sacrifice of precision. This inverse ratio measurement should be tried when the required exciting current appears to exceed the capacity of the TTR generator, when none of the low-voltage windings is rated to carry the full capacity of the transformer, when the rated voltage of the winding is so low (below 100 volts) that excitation at 8 volts is of an order of magnitude near to normal rated excitation, and when load ratings are so small that magnetizing current would approach the magnitude of load current.

The secondary leads (H1, H2) may be extended as required by any convenient conductor. Since the measurement is made by null balance there is no significant current in the secondary leads.

4. The X_2 clamp and the H_2 clip (marked in red) have same instantaneous polarity. Red connections are on same side (opposite each other) in transformers having subtractive polarity and are crossed when polarity is additive.

When polarity is reversed or ratio is extremely unbalanced the current indicated by the ammeter on the TTR Set will include a load component in addition to the exciting current. In this case turning the fourth dial to "open" will cause the ammeter indication to drop sharply as the secondary burden is thereby removed.

Autotransformers have essentially subtractive polarity.

The exciting current of the reference transformer may be observed for the purpose of checking internal continuity by closing the clamp screws on the anvils of

the X1, X2 clamps without connecting to a transformer. The excitation connection is insulated from the supply connection at the clamp.

5. Set the four dial switches to zero, (i. e. 00.000). Turn the hand crank slowly 1/4 to 1/2 turn. Detector pointer should swing sharply to the ***left.*** If pointer swings to the right, connections are reversed, or transformer has reversed polarity. Keep all dial switches at zero for this test.

Note that the galvanometer is so polarized that the pointer position changes in a clockwise direction with an increase of the ratio setting of the TTR Set. Hence to cause the pointer to move in the direction required to approach balance, the dials are turned in the same direction.

Reversed polarity has the effect of a "negative" ratio. Hence when the polarity of connections between the test transformer and the TTR reference transformer is reversed the galvanometer deflects in the positive direction indicating that a negative correction is required to attain balance.

6. While turning crank ***slowly***, increase ratio in first (left) dial switch till detector pointer swings to right. Turn back to highest position where pointer swung to left.

One of the unique features of the TTR Set is its practically "automatic" sensitivity control. As balance is approached the operator naturally tends to turn the crank faster, raising the excitation voltage and thereby increasing sensitivity. A sudden mis-match between the transformer under test and the reference transformer throws a load on the generator and the operator naturally reduces speed and sensitivity.

7. In same manner, increase ratio successively in second and third dials.

The first three dials operate switches which select exact tapped sections on the reference transformer. The fourth dial, however, is a continuously adjustable voltage divider with a full-scale length equal to the smallest increment on the transformer. (See Fig. 4)

8. Increase ratio in fourth dial, adjusting to a null balance (center zero reading of the detector) while the speed is raised and held at approximately 8 volts excitation.

In actual practice, no two transformers can be balanced to a perfect null since harmonic components and phase displacements are superposed on the unbalance current because of differences in excitation characteristics of the transformers. It is desired to detect the point of balance at which the induced potentials of test and reference transformers are equal. These induced potentials are assumed to be in phase with one another (opposing) and with the applied exciting potential. (See Page 50) The component of current resulting from a difference between these induced potentials is essentially in phase and becomes zero when the ratios are equal.

The detecting system is phased to the supply by means of the synchronous commutator so that the quadrature component is suppressed. The harmonic components go thru the detecting system with practically no effect on the d-c galvanometer.

9. The turn ratio of transformer under test is then read directly from a ***summation*** of the dial switch indexes, for example: 63.745. Decimal point is always between the second and third dials.

The ratio indicated on the dials is the ratio of the TTR reference transformer. After null balance has been attained it is also the ratio of the transformer under test subject to accuracy considerations set forth on page 25.

Tests have been made on transformers having ratios higher than the available range (130) of the TTR Set. This is accomplished by means of two sets and special techniques. For information write to us.

10. For testing polyphase transformers, see INSTRUCTION MANUAL 55-J.

For the purpose of ratio tests each phase of a polyphase transformer is usually treated as a separate transformer. This approach depends upon having access to each phase separately and associating HV and LV windings in proper relation as equivalent single phase transformers located on the same core-leg. When only one phase-leg is excited and other windings are clear of

burden the return flux from the excited leg is divided among all inactive legs. Hence any measurement made on a winding situated on a core-leg carrying partial flux is irrational (See Page 38). The polyphase vector diagram is helpful in determining which windings are in related phase positions.

Delta-connections should be opened. Y-connected transformers should be tested line to neutral so as to accomplish separation of the phases. On transformers having internal delta connections, the delta may often be opened by stopping one tap changer between contacts when tap changers are available for each phase separately.

Experience thus far has indicated that the ratio of some polyphase transformers may be tested successfully by means of TTR Set without separating phases. (See Page 41)

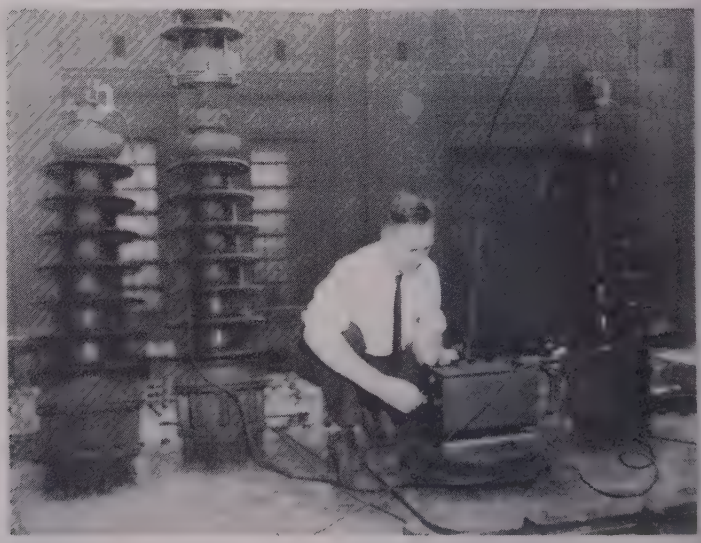


FIGURE 5. Measuring turn ratio on a large transformer.
Photo by courtesy of Philadelphia Electric Co.

Safety Precautions

The transformer under test must be isolated from all other energized equipment.

Be sure there is no magnetic or capacitive coupling with nearby energized lines or equipment.

Observe all safety rules and switching procedures which apply to the particular equipment under test.

If any safety ground introduces a burden or a short-circuit, it must be removed with suitable precautions.

The TTR Set is designed for use by one man only, and as such involves no hazard, for it is extremely unlikely that a man would operate the instrument and at the same time come in contact with the connecting leads. When the operator is changing connections he is not turning the crank of the generator.

When two or more men are present, the operator must not turn the crank until everyone is away from exposed connections. With high ratio dial settings the potential at the secondary (H_1 and H_2) clips may be on the order of 1000 volts a-c.

Because of the small amount of electrical energy actually available from the generator, equipment under test cannot be damaged by the TTR Set. Any possible danger from electric shock is more in the nature of surprise and consequent effects than from the actual shock itself.

All circuits within the TTR Set are highly insulated from one another and from the case. Grounding the case is considered unnecessary but may be done if desired.

NOTES

Section III

ACCURACY

The turn count of the reference transformer is absolutely correct as indexed on the ratio dials. When null balance is obtained, the ratio shown on the dials is read as the ratio of the transformer under test, subject to consideration of the effects of excitation and other conditions discussed in this manual.

Accuracy of turn ratio tests as made in the field on rational transformers of the power and distribution classes depends on a number of considerations other than the instrument used for the test. Since these considerations are known and understood by persons familiar with transformer operation, some references in subsequent paragraphs will be abbreviated by omitting explanation of details considered to be well known.

In ordinary field use turn ratios as measured by the TTR Set may be expected to be accurate within one part per thousand for ratios above unity and to the nearest division (0.001) for ratios below unity. When the conditions of test are favorable the overall accuracy may approach the smallest dial division as a limit, even at high ratios such as 100.000 of which the smallest dial division represents 0.00001 of the indicated ratio.

The accuracy of the measurement is dependent not only on the inherent accuracy of the instrument but also on the characteristics of the transformer under test. There are two significant types of error to be considered, which are potential drop in the excited windings and leakage in the magnetic circuit.

To visualize the nature of these errors, first assume that the transformer to be tested by means of the TTR Set be an "ideal" one. By "ideal" we mean particularly a transformer having no magnetic leakage and having

either zero resistance in its conductors or zero exciting current. If such a transformer were actually possible the errors of the TTR Set could be measured directly.

Connected to an "ideal" transformer the TTR Set would have a potential drop error in the exciting winding and its leads. The induced potential in the exciting winding differs from the terminal voltage by a small amount depending upon the magnitude of exciting current and the effective resistance of the exciting winding. The potential drop of the reference transformer including its leads is less than 0.0002 per unit (1 part in 5000) or 0.0015 volts at 8 volts excitation.

The transformer under test, however, is not "ideal" and has a potential drop in its exciting circuit which depends upon the characteristics transformer. Since the ratio test is made with essentially zero secondary current, the current density in the excited winding is only a small fraction of the current density for which the conductors were designed and the potential drop will therefore be small. In power transformers between 1 and 50,000 kva sizes the potential drops at 8 volts excitation have been observed to be in the order of 0.001 to 0.010 volts or 0.00012 to 0.0012 per unit (1 part in 8000 to 1 part in 800).

Under test conditions the potential drop errors of the test transformer and the reference transformer tend to compensate one another. Hence, the net error due to potential drops depends upon the difference between potential drops of the reference transformer and the transformer under test. Furthermore the detector system is so phased that the component of potential drop which appears in the vector diagram (Section IV) as an error in ratio is less than one quarter of the gross potential drop.

Referring again to the "ideal" transformer to which the TTR reference transformer might be connected, one would observe a further error in ratio which can not be accounted for as potential drop. This may be identified as magnetic error resulting from leakage.

In the TTR reference transformer flux leakage has been minimized by selection of core dimensions and

material, by distribution of exciting ampere-turns, and by other design features. The magnetic error in the reference transformer is difficult to observe on the TTR dials.

Magnetic error also occurs in practical power and distribution transformers. The relative flux leakage depends, of course, on the geometric proportions of the core and the exciting windings. In an extreme case a variation of induced potential per turn in the order of 0.04 per unit has been observed as shown on Page 37.

Referring again to the vector diagram, it appears that the component of leakage reactance drop which contributes to the ratio error is more than 0.97 of the gross reactance drop.

Experience thus far, however, indicates that the order of magnitude of ratio error to be expected on ordinary transformers may be estimated as follows:

$$\Delta n = \frac{n - n'}{n'} = \frac{e - e'}{V_p - e} \qquad (1)$$

where:

Δn = per unit error in ratio measurement

V_p = applied potential at excitation terminals of both transformers (terminals to which TTR clamps are attached become the equipotential reference datum)

e' = potential drop in exciting winding of reference transformer

e = potential drop in excited winding of test transformer

n' = observed ratio, i.e., ratio of actual turns connected in TTR reference transformer at null balance

n = true ratio of test transformer (unknown)

When the potential drop (e) in the test transformer is less than the potential drop (e') of the reference transformer, the ratio (n) will be lower than the observed ratio (n') and Δn will be negative.

When the magnetic leakage of the transformer is higher than is usual for modern power and distribution transformers, the ratio error will be greater than is indicated by equation (1) above. The correction formula given here is, therefore, to be considered only as a practical guide to estimate the order of magnitude of error. Further data on correction methods will be published in due course.

In considering the practical accuracy of the measurement one must be guided by the characteristics of the transformer under test. Consideration of the structure of the transformer may indicate that the ratio must correspond to whole numbers of turns, or in the case of distributed core transformers to multiples of definite fractions of turns. Hence it is well to determine the ratio increment which corresponds to one turn. This elementary increment may be estimated from data on the nameplate of the transformer by methods which are explained on Page 52. After determining the elementary ratio increment it is obvious that ratio measurements need be carried only to a precision corresponding to the nearest turn or the nearest elementary fraction of turn.

Other sources of error have also been minimized in the TTR Set. Burden of any sort (See Page 59) affects terminal potential of the transformer according to its regulation characteristic. Burden in the ratio test by the TTR Set is eliminated by the null balance system. Faulty conditions in the transformer under test may impose burden, which will be indicated by increased exciting current and increased mechanical load on the generator-crank. In such circumstances the TTR Set functions to indicate the presence of burden conditions on the transformer under test and the ratio measurement -- per se -- is not significant.

Insulation resistance of the TTR Set has been kept

high, especially by attention to the surface leakage distances on the reference transformer tap switches. Experience indicates that a shunt of approximately 0.1 megohm may be tolerated across high side terminals without introducing excessive burden from leakage. The effect of leakage, however, is not great enough to be useful as a test of insulation.

Observation errors occur in any test performed by a human being. The TTR Set, fortunately, operates in such a way that there is little opportunity for personal errors to become significant. The first three decade dials are positively indexed in steps. The fourth dial has antiparallax index so that errors will be minimized. Galvanometer sensitivity is adequate to support accuracy of far better than 1 part per thousand.

Two characteristics which will be observed in the TTR Set may cause minor differences in the reproducibility of observations. These are "speed effect" and "apparent change of sensitivity". The differences occur in the sixth and occasionally the fifth significant figure, well beyond 1 part in 10,000. They are mentioned because the nature of the decade arrangement is such that balance may be carried out to the sixth figure on high ratios and confusion may result unless the operator is aware of the importance of rounding off the ratios to reasonable limits of precision. (See discussion of precision).

"Speed effect" in varying degree may be observable on ratios above 10 (occasionally as low as 6). The so called "speed effect" is apparent as a change of null balance ratio in which null is obtained at slightly different ratios with changes of applied potential. The tentative explanation is that when the magnetization curves of the reference and the test transformers have different slopes, the magnetizing currents change at different rates and therefore the difference between respective potential drops (IR) changes with speed. The "speed effect" is not apparent below ratios of 10 because it is normally in the order of parts in 100,000 and hence is lost when

only 4 significant figures are shown on the dials. The "speed effect" is not important because it affects the fifth figure in a measurement significant to approximately the fourth figure.

Cases of abnormally high "speed effect" may usually be traced to high resistance connections in the excitation circuits. Hence when "speed effect" is observed all joints in the excitation circuit should be checked for cleanliness and other aspects which contribute to good conductivity. The special anvils on the C-clamps of the TTR Set are designed to penetrate ordinary surface films. The isolation of supply (S) and excitation (X) circuits thru the C-clamp places the contact resistance (between the anvil and the transformer terminal) in the excitation circuit of the reference transformer which has low, constant exciting current.

Abnormal "speed effect" may also occur when there is a fault (See Page 58) on the transformer such as a short circuit on part of a winding or an intermittent variation of any sort. Hence "speed effect" to any troublesome degree is an indication of abnormal conditions which should be investigated.

To obtain consistent and reproducible measurements it is intended that all tests be made at the level of excitation to which the reference transformer, galvanometer sensitivity, and other details of the TTR Set are adapted.

"Apparent change of sensitivity" of the galvanometer occurs at high ratios as a reduction in amount of pointer movement for an incremental change of ratio setting. The galvanometer (See Page 9) is a current instrument (0.2 - 0 - 0.2 ma) used as a null detector. Its deflection is approximately constant over the entire range of ratios for a given per unit change of ratio. At higher ratios, therefore, the galvanometer gives warning to the operator that balance in the fifth or sixth figure is beyond the reasonable limits of precision. Galvanometer sensitivity is adequate, however, to obtain balance if desired at any ratio to an increment of 0.001 on normal power and distribution transformers.

The decade dials of the TTR Set are subject to the same limitations as are those of any other decade-arranged apparatus. As additional significant figures are introduced to the left of the decimal point, the number of available figures in the measurement increases. Small steps required for low ratios are necessarily included at high ratios. The operator should "round off" the result to a reasonable precision, which depends upon the characteristics of the transformer under test. The TTR Set has been designed to make available the precision needed for practically any transformer of the "power" and "distribution" classes and therefore usually reads to a greater number of figures than is significant.

NOTES

Section IV

THE TRANSFORMER UNDER TEST

The application of the TTR Set to maintenance and winding procedures is no less important than its obvious application to checking specification ratios of power and distribution transformers. Successful interpretation of ratio measurements as a means of exploring the internal structure and condition of the transformer depends upon understanding of transformers and transformer practices more than upon the techniques of measurement. The simplicity of direct-reading ratio measurements by the TTR Set will make it easier to apply the experience and judgment of responsible men to these problems.

Rational Excitation

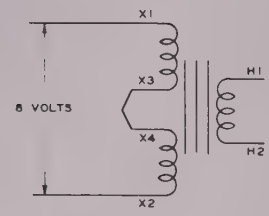
The TTR Set will measure turn ratio in any structure which is electrically equivalent to a rational transformer. Since no transformer is ideally perfect, rationality is a matter of degree.

For the purpose of precision turn ratio measurements, a rational transformer may be defined as follows:

1. The winding chosen for excitation should be suitable for full rated load output at a usable impedance or regulation.

2. The excited winding as in (1) should include approximately half of the total copper in the (single phase) transformer and the excited turns should be distributed throughout the window.

3. The magnetic core should be properly stacked and complete without magnetic shunts or air-gaps.



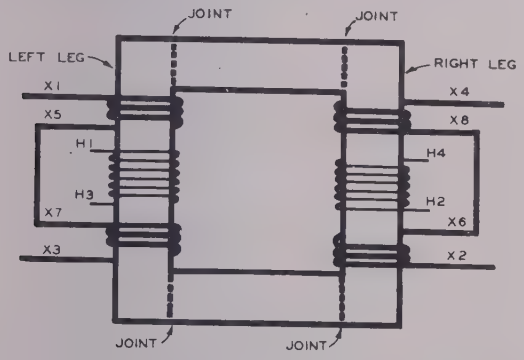
SERIES CONNECTION MULTIPLE CONNECTION

Test	A	B	C	D
Connection (Excited Winding)	Series (X1-X2)	Multiple (X1-X2)	One Half (X1-X3)	Other Half (X4-X2)
Applied Exciting Voltage	8	8	8	8
Turns Excited	2T	T	T	T
Resistance of Excited Winding	2r	0.5r	r	r
Turns High Side	T'	T'	T'	T'
Nominal Ratio	n	2n	2n	2n
Volts per turn	e	2e	2e	2e
Flux	Φ	2Φ	2Φ	2Φ
Ampere turns required	NI	2NI	2NI	2NI
Magnetizing Current	i	4i	4i	4i
Potential Drop	2ir	2ir	4ir	4ir
Example:				
Measured Ratio of H1-H2(Fig.7)	29.995	59.998	59.477	59.49
Measured Ratio of H1-H3(Fig.7)	15.001	29.995	29.97	29.47
Measured Ratio of H4-H2(Fig.7)	14.997	29.995	29.46	29.97

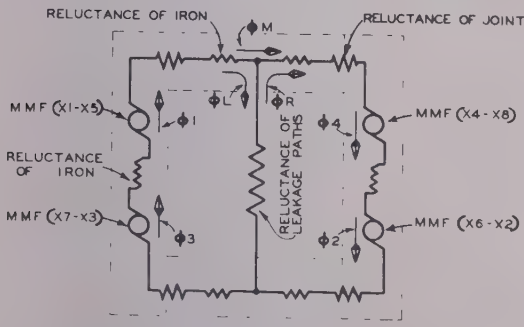
FIGURE 6. Effect of Exciting on Half-winding demonstrated by Multiple x Series Transformer.

When making ratio tests there must be no condition appreciably loss-producing in nature (See Page 58) and the required exciting current must not be in excess of the TTR generator capacity (See Page 10).

The significance of distribution of exciting ampere turns on the core may be demonstrated very simply by making four ratio tests on one high-voltage winding of a multiple x series transformer, exciting on the low-voltage winding in several ways as indicated in Fig. 6.



PHYSICAL ARRANGEMENT OF TYPICAL TRANSFORMER



ANALOGOUS ELECTRICAL CIRCUIT

FIGURE 7. Multiple x Series Transformer Showing Arrangement of Magnetic Circuit and Analogous Electric Circuit.

The ratio measured with series connection should be exactly half the ratio measured with multiple connection (A and B in Fig. 6) but the ammeter of the TTR Set will indicate a four-fold increase of the exciting current.

When only half of the winding is excited the IR drop is doubled as indicated in Fig. 6. Usually the IR drop will account for only a small part of the difference between ratios measured with half of the core excited and with fully distributed excitation. The magnetic leakage flux distribution in the transformer varies according to the location of the applied magneto-motive forces. With only half the winding excited and the ampere-turns applied to only one leg, flux in the other leg will be less than normal. This effect can be demonstrated by considering the arrangement shownin Figure 7 and the analogous electrical circuit. By comparing the magneto motive force of each coil to an electric generator, the reluctances to resistors, and the flux to current one may readily visualize the effect of omitting one or more generators from the circuit. In the same way, when ampere turns are applied to one leg only, the leakage flux is greater than that when ampere turns are distributed on both legs.

The distortion of leakage flux paths when excitation is applied to only one leg of a transformer may be illustrated by considering the reason for transposing the windings in a transformer arranged for 3-wire connection. On such a transformer the load may be unequally divided without serious voltage unbalance if the windings are transposed so that half the load from each side of the 3-wire service is placed on each transformer leg. Ratio tests on a 3-wire transformer excited on one half of the LV winding (transposed in the transformer) would not be subject to the leakage flux errors that would occur in a 2-wire transformer without transposition of the windings. The potential drop would, however, be reduced by excitation on the full winding.

By reference to Fig. 11, the equivalent circuit, it will be apparent that the leakage reactance determines

the difference between induced potentials in the primary and secondary windings. Since symmetrical distribution of windings is recognized as necessary in order to minimize leakage reactance, it follows that accuracy in ratio measurements likewise depends upon distribution of the exciting ampere-turns.

The effect of leakage is to produce differences in the induced potentials of individual turns which may be observed by actually measuring the ratio of each disc coil within a winding. The transformer shown in Figure 8 is typical of a class of transformers in which measured ratios are lower than the actual turn ratio. Note that the window is narrow (2:5) compared to its length.

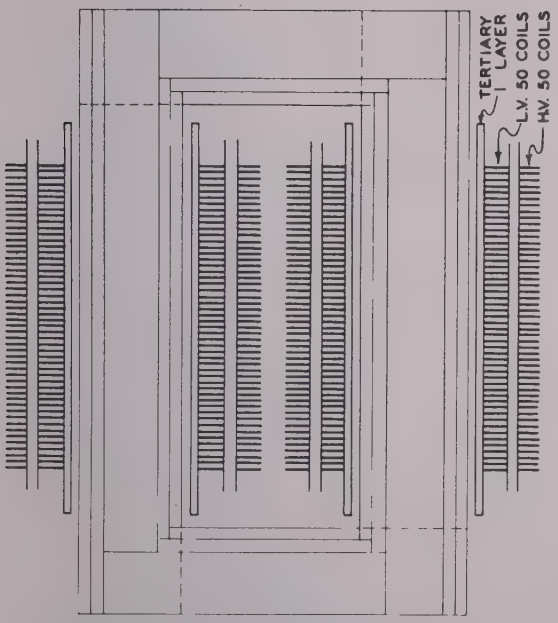


FIGURE 8. Typical Transformer, 1850 kva, 63.5 KV - 25.4 KV - 2.4 KV, OISC.

	COILS		ACTUAL NUMBERS OF TURNS HV/LV	TRUE RATIO (REFERRED TO LV)	MEASURED RATIO	DEVIATION INCREMENT		PER UNIT
Neutral Leg	1+2	(top)	25+25/500	0.10000	0.097	-0.003	(1.5 turns)	0.03
	3+4		50/500	0.10000	0.097	-0.003	(1.5 turns)	0.03
	5+6		50/500	0.10000	0.098	-0.002	(1 turn)	0.02
	7+8		50/500	0.10000	0.098	-0.002	(1 turn)	0.02
	9+10		50/500	0.10000	0.099	-0.001	(1/2 turn)	0.01
	11+12		50/500	0.10000	0.099	-0.001	(1/2 turn)	0.01
	13+14		50/500	0.10000	0.100	0.000		-
	15+16		50/500	0.10000	0.100	0.000		-
	17+18		50/500	0.10000	0.100	0.000		-
	19+20		50/500	0.10000	0.100	0.000		-
	21+22		50/500	0.10000	0.100	0.000		-
	23+24		50/500	0.10000	0.100	0.000		-
	25+26		50/500	0.10000	0.100	0.000		-
	27+28		50/500	0.10000	0.100	0.000		-
	29+30		50/500	0.10000	0.100	0.000		-
	31+32		50/500	0.10000	0.100	0.000		-
	33+34		50/500	0.10000	0.100	0.000		-
	35+36		50/500	0.10000	0.100	0.000		-
	37+38		50/500	0.10000	0.100	0.000		-
	39+40		50/500	0.10000	0.099	-0.001	(1/2 turn)	0.01
	41+42		50/500	0.10000	0.098	-0.002	(1 turn)	0.02
	43+44		50/500	0.10000	0.098	-0.002	(1 turn)	0.02
	45+46		50/500	0.10000	0.097	-0.003	(1.5 turns)	0.03
	47+48		50/500	0.10000	0.096	-0.004	(2 turns)	0.04
	49+50	(bottom)	50/500	0.10000	0.096	-0.004	(2 turns)	0.04
	Sum of increments				2.472	-0.028	(14 turns)	
	Whole N. leg		1250/500	2.50000	2.464	-0.036	(18 turns)	0.01

Line Leg	(top)	(surge ring)	-	-	-		
	1+2	5+8/410	0.03171	0.030	-0.002	(1 turn)	0.06
	3+4	8+8/410	0.03902+	0.037	-0.002	(1 turn)	0.05
	5+6	11+11/410	0.05366	0.051	-0.003	(1 turn)	0.06
	7+8	11+16/410	0.06585+	0.063	-0.003	(1 turn)	0.05
	9+10	16+16/410	0.07805	0.076	-0.002	(1 turn)	0.03
	11+12	16+25/410	0.10000	0.097	-0.003	(1 turn)	0.03
	13+14	25+25/410	0.12195+	0.120	-0.002	(1 turn)	0.02
	15+16	50/410	0.12195+	0.120	-0.002	(1 turn)	0.02
	17+18	50/410	0.12195+	0.120	-0.002	(1 turn)	0.02
	19+20	50/410	0.12195+	0.121	-0.001	(1/2 turn)	0.01
	21+22	50/410	0.12195+	0.121	-0.001	(1/2 turn)	0.01
	23+24	50/410	0.12195+	0.121	-0.001	(1/2 turn)	0.01
	25+26	50/410	0.12195+	0.122	0.000		-
	27	25/410	0.06098	0.061	0.000		-
	28+29	50/410	0.12195+	0.122	0.000		-
	30+31	50/410	0.12195+	0.122	0.000		-
	32+33	50/410	0.12195+	0.121	-0.001	(1/2 turn)	0.01
	34+35	50/410	0.12195+	0.121	-0.001	(1/2 turn)	0.01
	36+37	50/410	0.12195+	0.120	-0.002	(1 turn)	0.02
	38+39	50/410	0.12195+	0.120	-0.002	(1 turn)	0.02
	40+41	50/410	0.12195+	0.120	-0.002	(1 turn)	0.02
	42+43	50/410	0.12195+	0.119	-0.003	(1 turn)	0.02
	44+45	50/410	0.12195+	0.118	-0.004	(1 1/2 turns)	0.03
	46+47 (bottom)	50/410	0.12195+	0.117	-0.005	(2 turns)	0.04
	Sum of increments			2.460	-0.042	(17 turns)	
	Whole L. leg	1026/410	2.50244	2.465	-0.037	(15 turns)	0.01
	Both legs (series)	2276/910	2.50110	2.490	-0.011	(10 turns)	0.004

FIGURE 9. Variation of Induced Potentials in Individual Coils.

On each leg there are approximately 50 HV and 50 LV disc coils. In Figure 9 the measured ratio of the whole HV winding with excitation on the whole LV winding may be compared to measurement of each leg of the HV winding with respect to its corresponding section of the LV winding. In this case the error introduced by partial excitation is appreciable.

The variation of induced potentials with position is apparent from the comparison of measured ratio to true ratio for each pair of coils. The data given are transcribed from the test log. Note that the sum of the increments in one group is larger than the corresponding measured ratio of the whole winding while in the other group it is smaller, which suggests that rounding off the observations to the third decimal place may be responsible for inability to show the equality of the sum to its parts. Unfortunately incremental data were not obtained with fully distributed excitation while the transformer was available.

The magnetic errors illustrated in Fig. 9 are unusually large and are not attributed to design but indicate how easily one may be misled by asymmetrical excitation during ratio tests.

Ratio tests on several similar transformers will show consistent tendency to be "off" ratio by a definite amount which is the resultant of potential drop and flux leakage errors. This difference may be either positive or negative and in most cases will be negligible. For transformers of identical form and size the characteristic ratio will not vary unless the actual turn counts are different. The deviation due to a change of 1 turn in the winding will be several times as large as the errors mentioned.

Sizes and Ratings

The TTR Set has been designed to make turn ratio measurements on power and distribution transformers from 1 kva to 50,000 kva and upwards, single phase,

rated from 110 volts to 110,000 volts and upwards. Other sizes and special types may be tested. The most important limitation on sizes and types which may be tested is the excitation condition during test.

Special limitations pertaining to those few transformers which require high magnetizing current or which have unusual magnetic leakage have been discussed elsewhere in this manual. In such transformers the turn ratio may be investigated comparatively. Comparisons may be made between sections of a given transformer, between two similar transformers, or between successive tests on the same transformer. For this class of work the accuracy is limited but the ability to obtain balance and measure ratio to the third decimal place can be used effectively in maintenance and trouble-shooting work. High magnetizing current should not be confused with "burden" (See Page 58) which may be distinguished by the high mechanical torque required to supply energy in a loaded winding.

It is helpful to remember that there must be a reason whenever the generator "cranks hard". The reason may be apparent as a characteristic of the transformer under test. Otherwise there is something unusual which will be of interest in determining the condition of the transformer. When the transformer is under burden the test is not a test of turn ratio since the regulation characteristics of the transformer are included. Under such conditions the TTR Set serves a useful purpose in investigating the condition of the transformer.

Polyphase Transformers

The Model 2 TTR Set may be used to measure the ratios of individual phases of polyphase transformers. Special techniques are needed to isolate the phases when delta connections can not be opened or when neutral connections are not accessible. These methods do not require additional equipment other than wiring materials which are readily obtained. The methods which follow

are applicable to various situations, but should be considered only as suggestions since the data presently available are too few to be conclusive.

For consideration of ratio tests, polyphase transformers may be divided into two groups as follows:

(1) Polyphase units on a unit core structure but having accessible terminals for each phase separately.

    (a) Units in good condition
    (b) Units having faults

(2) Polyphase units in which phase-to-phase interconnections are inaccessible.

    (a) Units in good condition
    (b) Units having faults

The first group, comprising those polyphase units having accessible terminals for each phase separately, may be considered as individual single-phase transformers, but the consolidation of core structure will usually introduce differences of magnetic leakage conditions from phase to phase. Consideration of "rational" excitation, of proportionality between copper and iron, and of dimensional concepts will be based on polyphase practices comparable to the suggestions given elsewhere in this manual. Generally it is assumed that the terminals of each phase are connected individually to windings on the same core-leg and that the core-legs each carry windings of only one phase. Exceptions such as 3- to 12-phase zig-zag connections must be accessible as equivalent single-phase groups or be considered under the second group.

Even tho phase terminals are individually accessible the presence of a fault may complicate the interpretation of ratio data. If, during ratio tests, a short circuit exists on any portion of any winding in a polyphase transformer, the fault will dissipate some energy

depending upon the potential induced and the resistance included. The flux linkages and the corresponding potentials will be less when the fault is on an inactive phase than when it is on the phase under test, but in either case the measured ratio will be affected. To obtain useful indications of the extent and location of such faults comparisons are made between phases in much the same way as is done to determine which section of a single phase transformer is affected. It follows, therefore, that one depends not only on the instrument but also upon his knowledge of transformer characteristics in such trouble-shooting.

The second group, in which individual phase connections can not be separated, require the application of special polyphase techniques. In general these techniques are intended to provide a connection by which a portion of the polyphase transformer is caused to act as a rational single phase unit.

When the delta connection can not be opened at the terminals or by manipulating the tap changers, the ratio test may be applied to each phase with the other phases connected. In three-phase YΔ transformers the inactive phases are excited in series with polarity opposite to that of the active phase so that the inactive legs each carry half the flux of the active leg. The ratio of the active leg is measured line-to-neutral. If the phases are balanced no burden is produced.

A method for making tests on YΔ transformers with closed delta and inaccessible neutral is diagrammed in Fig. 10, showing the relations between phase-leg positions, terminal vector diagram, and connections to be made. The relations established in this diagram may be summarized as follows:

X Red and H Red are connected to same phase and polarity

X Black is connected to same phase as X Red and H Red but to opposite polarity

H Black is connected to HO THRU EITHER OF INACTIVE PHASE TERMINALS by means of the short circuit device

JUMPER short circuits LV side on same phase leg as H Black.

In the diagram excitation is applied equally to leg 1 and leg 3 with short circuit on leg 2. Hence terminal voltage across leg 2 (X2-X3) is zero. With equal excitation all flux is confined to the two excited legs. The objective

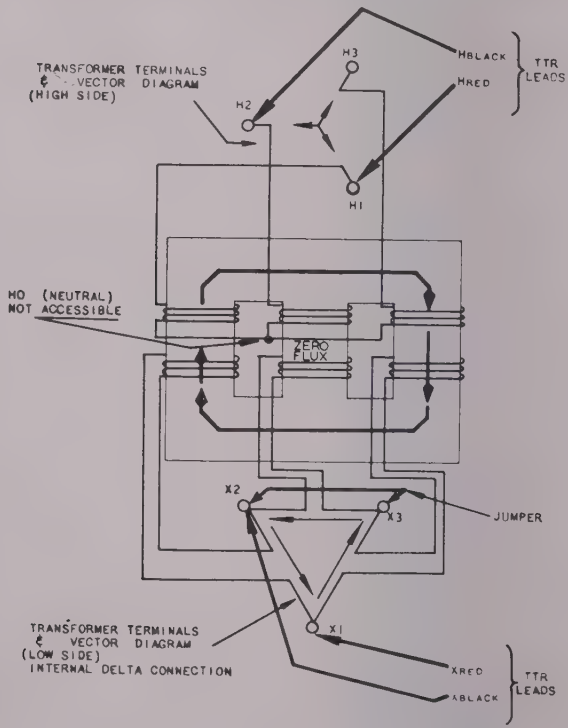


FIGURE 10. Diagram of YΔ Transformer Showing Connections for making Ratio Tests with Delta Closed and Neutral Inaccessible.

is to render one phase-leg so inoperative that it may be used as a connecting lead to gain access to HO which is accomplished by directing all of the flux into one inactive leg and using the other as the lead. The reasoning will be apparent from notes on the diagram.

Obviously the device of Figure 10, is subject to some magnetic leakages and potential drops which are not indicated. At present, however, it appears to be practical.

Available data show a tendency among measured ratios on three-phase transformers to be slightly low as compared to nominal ratios, but the deviations are not much greater than the tolerances usually accepted for ratio specifications. Since none of the data includes a comparison to verified turn-count it is impractical to make a definite statement at this time.

Another interesting observation is a variation from phase to phase, in which the measured ratio on the center leg tends to be higher than that of either outer leg with generally smaller variations between the two outer legs. These data also are not conclusive.

These trends have been observed on three-phase YΔ and ΔY transformers tested with deltas either opened or closed and from line to neutral on Y side. When tested with deltas both closed and opened on the same transformer, the measured ratio is higher with delta open, but there may be exceptions.

Vector Diagram and Equivalent Circuit

The equivalent circuit* for a transformer, Fig. 11, is given in conventional "Π" form. The "T" form of equivalent circuit (more familiar to some readers) is mathematically interchangeable with respect to the four terminals of the network but is not so readily adaptable to representing the behavior under no burden conditions. The simplified "L" form of equivalent

*L.F. Blume, (Editor), Transformer Engineering, John Wiley & Sons, Inc., 1938, p.67; C. E. Magnusson, Alternating Currents, McGraw Hill Book Co., Inc., 1926, Chapter XII; O.G.C. Dahl, Electric Circuits, Vol. I, McGraw Hill Book Co., Inc., 1928, Chapter II.

circuit is a practical approximation which makes no separation of exciting components.

In the equivalent circuit the primary and secondary series resistances, R_p , and R_s , are shown with three reactances, X_p , X_s , and X_l , corresponding to primary, secondary, and leakage fluxes respectively. The core loss component associated with each main flux is represented by a shunt resistance. The equivalent circuit does not show the transformation ratio nor the isolation of primary from secondary. It is customary to represent the ratio as unity by taking potentials in volts-per-turn and currents in ampere-turns with resistances and reactances on a per unit basis. Physically, all of the current components are present in the primary winding.

The secondary current, I_s, is zero when balance is attained for ratio tests. The vector diagram, Fig. 13, differs accordingly from the usual vector diagram with only the exciting current components being included. To avoid distortion of the angles between potential (also flux) vectors, it has been necessary to replot the vector diagram in Fig. 14 to a scale which permits separation of the potential vectors.

In these vector diagrams, as in conventional practice, the vectors are represented on a per unit basis. The component of primary voltage opposing the primary induced potential is E_p found by subtracting vectorially the primary resistance drop from the primary terminal voltage. Since the transformer is considered under no-load condition, the secondary induced potential becomes the secondary terminal voltage.

The flux triangle is shown with sides proportional and perpendicular to the respective potentials. The magnetic circuit of the transformer may be considered in two parts, the primary and secondary flux portions. The difference represents the leakage, being that which exists wholly or partly in the air. It follows that there are two exciting ampere-turns corresponding respectively to the primary and secondary fluxes. It is con-

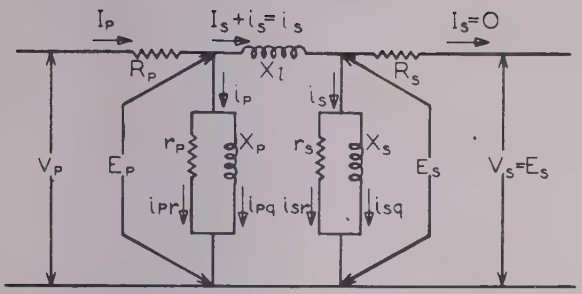


FIGURE 11. Equivalent Circuit of Transformer when Secondary Current is Zero.

Vector:	In Transformer Under Test		In TTR Reference Transformer	
	Primary	Secondary	Primary	Secondary
Terminal Voltage	V_p	V_s	V'_p	V'_s
Induced Potential	E_p	E_s	E'_p	E'_s
Potential Drop due to Resistance	$I_p R_p$		$I'_p R'_p$	
Potential Drop due to Leakage Reactance	$i_s X_l$		$i'_s X'_l$	
Total Current	I_p	I_s	I'_p	I'_s
Total Exciting Current	I_p		I'_p	
Primary Component of Exc. Current	i_p		i'_p	
Secondary Component of Exc. Current		I_s		i'_s
Magnetizing Component of Current	i_{pq}	i_{sq}	i'_{pq}	i'_{sq}
Energy Component of Current	i_{pr}	i_{sr}	i'_{pr}	i'_{sr}
Flux	Φ_p	Φ_s	Φ'_p	Φ'_s
Leakage Flux		Φ_l		Φ'_l
Effective Resistance	R_p	R_s	R'_p	R'_s
Leakage Reactance		X_l		X'_l
Reactance	X_p	X_s	X'_p	X'_s
Equivalent Resistance of Losses	r_p	r_s	r'_p	r'_s

FIGURE 12. Symbols Used in Equivalent Circuits and Vector Diagrams.

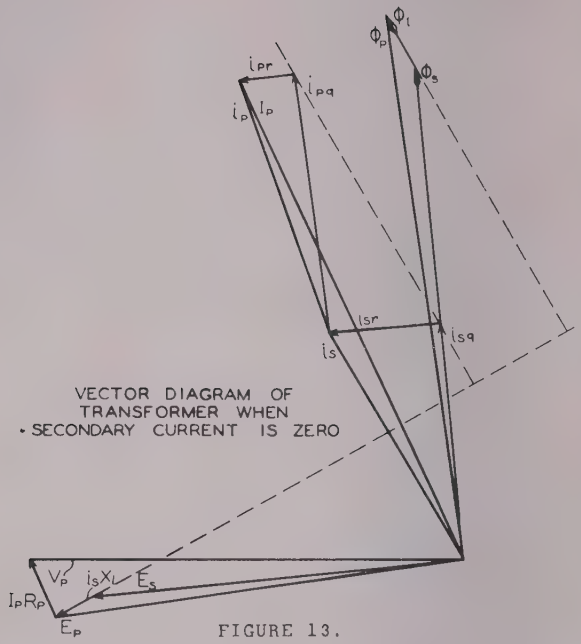


FIGURE 13.

venient to divide the exciting current into a primary and a secondary component, each of which is further divided into a magnetizing component in phase with the corresponding flux and an energy component in phase with the induced voltage. These components are represented in the current diagram, the two magnetizing components being proportioned according to the respective fluxes. Since both the primary and secondary exciting components exist actually in the primary winding the current vectors are added to represent the total exciting current which is also the total primary current.

By comparison of Fig. 13 to Fig. 14 it will be apparent that variations of the resistance, R_p, affect the magnitude and angle of terminal voltage, V_p, relative to induced potential, E_p, without altering any of the relations in the flux and current diagrams. On the

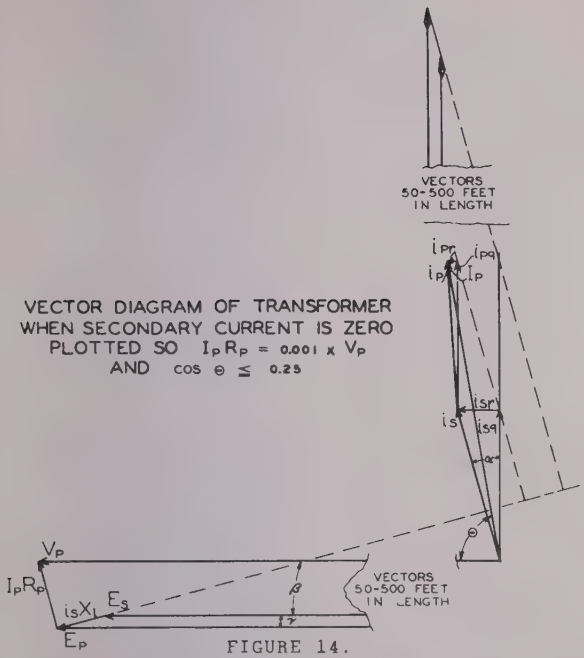


FIGURE 14.

other hand, variations of the leakage reactance affect the relations among all parts of the diagram, effectively determining the relative magnitudes of primary, i_{pq}, and secondary, i_{sq}, components of current as well as the phase angle between primary, E_p, and secondary, E_s, induced potentials.

Modification of the dimensions or the magnetic properties of a transformer does not alter the total flux required to induce a given potential, but changes the exciting ampere-turns required to produce the flux. Hence, the relative magnitudes of the components of exciting ampere-turns are determined by the dimensions and magnetic properties of the transformer. The secondary magnetizing and energy components are determined by those characteristics which govern the leakage paths, while the primary components reflect saturation effects.

Vector	In typical power transformers	In TTR reference transformer
V_p (reference)	1.0	1.0
$I_p R_p$	from 0.001 to 0.0001	0.0002 approx.
$\cos \theta$	less than 0.25	0.2 approx.
$\tan \beta$	from 0.001 to 0.0001	
$\tan \gamma$	from 0.0002 to 0.00005	
β	$<0.1°$	
γ	$<0.01°$	

FIGURE 15. Relative Magnitudes of Vectors and Phase Angles, applying to the Vector Diagrams.

The vector diagram and equivalent circuit of the TTR reference transformer are identical to those of the transformer under test. The magnitudes and angles, as indicated in Fig. 15, fall between the usual limits of variation among power and distribution transformers. In Fig. 16 and 17 the equivalent circuit and vector diagram are given for a transformer connected to the TTR Set.

Since vectors E_S and E'_S represent the per unit potentials (volts per turn) induced in the secondaries of the test transformer and the reference transformer respectively and since these probably will be neither

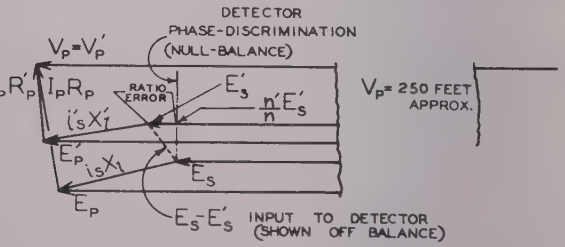


FIGURE 16. Vector Potential Diagram of Transformer Under Test connected to TTR Reference Transformer.

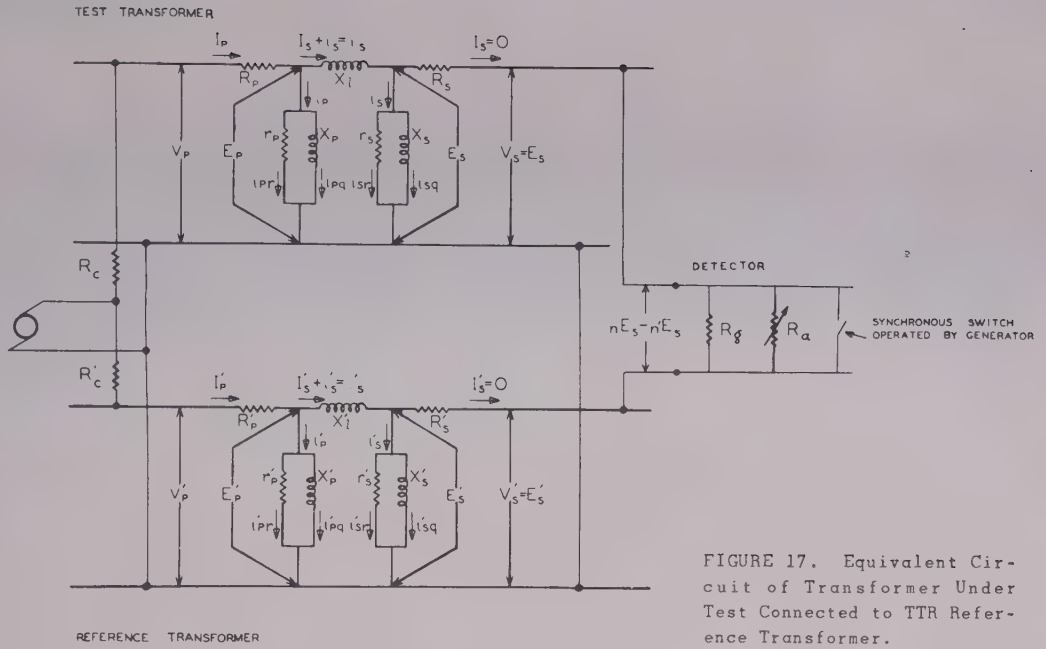


FIGURE 17. Equivalent Circuit of Transformer Under Test Connected to TTR Reference Transformer.

coincident nor equal, the null balance is obtained by adjusting the ratio n′, to make $n'E'_S = n E_S$ at balance. The residual quadrature component is suppressed by the commutator, accomplishing two objectives; namely, to achieve null balance instead of a minimum and to sense the polarity of unbalance.

The magnitude of the ratio error (n′- n) is dependent upon the vector sum of the respective resistance drops and reactance drops. The magnitude of the vector shown is reasonably typical and is considerably less than one part per thousand.

Estimating Turns

Often it is desirable to know how many turns are included in a transformer coil. The necessary degree of accuracy and precision in turn ratio measurements for practical application depends on how many turns there are in the transformer. More directly, the exact number of turns is of interest in winding replacement coils.

Several methods are available for estimating the number of turns in transformer coils. These methods depend upon familiarity with conventional transformer design and are reliable only to the extent that the transformer in question may be expected to follow usual practices. Another method of estimating turn count by measurement with the TTR Set is available when the transformer is untanked or the core is accessible.

Most transformer coils are wound in multiples of a full turn, but distributed core structures make possible the occurrence of fractional turns. In any transformer, therefore, each turn ratio is derived from two numbers which are either whole numbers or multiples of a symbol fraction. The smallest unit of turn count is determined by the structure of the transformer and may be converted readily into an elementary increment of ratio by

considering that:

$$\frac{N_s}{N_p} = \text{ratio}$$

where: N_s is the number of turns in the secondary
N_p is the number of turns in the excited winding.

Then the elementary increment of ratio, d, corresponding to one turn must be

$$d = \frac{1}{N_p}$$

or for N_d turns,

$$d = \frac{N_d}{N_p}$$

Note that so long as excitation is applied to the N_p turns, the increment of ratio $1/N_p$ corresponds to one turn in any winding.

If, however, the number of turns in the excited winding be changed, as in exciting first one winding and then another, there will be no common denominator and comparisons will be more complex. For field work in which direct comparisons are most useful, it is well be made all measurements of ratio with reference to one selected excited winding.

In some shops the winding specifications are accessible for reference. Such specifications usually include the turn-count of the coils in detail so that it is easy to determine the number of turns represented by any increment of ratio. When such data are available ratio measurements may be used to advantage in determining the location of faults or errors on a complete transformer.

Direct measurement of the turn count of a transformer, when the core is accessible as in open types or in untanked transformers, is accomplished by means

of a temporary winding. The resistance of the temporary winding is not critical since it carries no current at null balance. A convenient number of temporary turns should be selected, as 10, so that arithmetic will be simple. Large numbers will yield more accurate results. In distributed-core forms the temporary winding should preferably be applied to the same portion of the core as the normal windings.

The temporary winding is connected to the H terminals of TTR Set and its ratio with respect to the excited winding is measured in the usual way. Alternatively the temporary winding may be connected to add or subtract in series with any other winding. The ratio of a known number of turns having been measured, it is simple to compute the ratio increment for one turn and the number of turns in any winding. The ratio increment representing one turn is the same for all windings so long as all measurements are made with reference to the same excited winding.

The accuracy of such turn-count measurements is subject to consideration of the same factors that apply to any other ratio measurement. Generally the temporary winding should not be excited since it is difficult to make it satisfy the requirements for rational excitation.

Often the turn count specifications are not known and it is impractical to make the transformer available for measuring turn count. In such situations it may be helpful to estimate the order of turns to be expected on the transformer so that ratio data may be interpreted to reasonable limits of precision. The nomograph (Fig. 19)* relates turn count to size of power and distribution transformers according to the commonly used rule:

$$\frac{V}{T} = K\,(\text{kva})^{\frac{1}{2}}$$

in which

$\frac{V}{T}$ = volts per turn

kva = rating

K = coefficient, between 0.5 and 2.0

*The nomograph, Fig. 19, is shown as an example and may be used for rough estimates. For those who wish to use it, a larger and more complete nomograph is available on request.

To use equation (1) or Fig. 19 for estimating the number of turns in any winding of a transformer it is necessary to have the following:

(a) rated voltage
(b) rated kva
(c) reasonable assurance that the transformer is in this general design class.

Two examples are plotted on Fig. 19 from data pertaining to power and distribution transformers as given in Fig. 18. The pivot circle on the nomograph applies to 60 cps power and distribution transformers within limits of variation determined from the data presently available, which limits are represented by the radius of the pivot circle. Since the empirical coefficient, K, depends* upon frequency, total flux, and the reciprocal of ampere turns, it is to be expected that the pivot circle will not be applicable to other frequencies, unusual forms of magnetic structure, and other special cases.

The coefficient, K, will be larger for the larger sizes of transformers and larger for distributed cores than for ordinary "core-form" structures. Since the available data are limited the pivot circle shown in Fig. 19 should be interpreted as tentative. Most of the data, if not all, in Fig, 18 pertain to "core-form" transformers. As further data become available similar pivot circles may be added to the diagram to aid in estimating turn count on various transformer forms.

The reciprocal scale, 1/T, is given to facilitate estimates of the elementary increment of ratio corresponding to one turn.

*Alfred Still, Elements of Electrical Design, McGraw Hill Book Co., Inc., Second Edition. 1932, page 500.

DATA PERTAINING TO TURN-COUNT OF POWER

& DISTRIBUTION TRANSFORMERS

kva	WINDING VOLTAGE	NUMBER OF TURNS	COMPUTED V/T	COMPUTED K
3.5	7200	5640	1.28	0.68
	240	188		
	120	94		
5	12000	7600	1.58	0.71
	240	152		
	120	76		
7.5	2400	1120	2.14	0.78
	240	112		
	120	56		
7.5	6900	3840	1.80	0.66
	230	128		
	115	64		
25	2400	540	4.44	0.89
	240	54		
	120	27		
200	25400	1652	15.4	1.09
	2400	156		
500			26.1	1.17
	2400	92		
	1200	46		
	600	23		
500			27.3	1.22
	2400	88		
	1200	44		
	600	22		
1850	63500	2276	27.9	0.65
	25400	910		
	2400	86		
2000	44000	660	66.7	1.49
	13867	208		
	6933	104		

FIGURE 18.

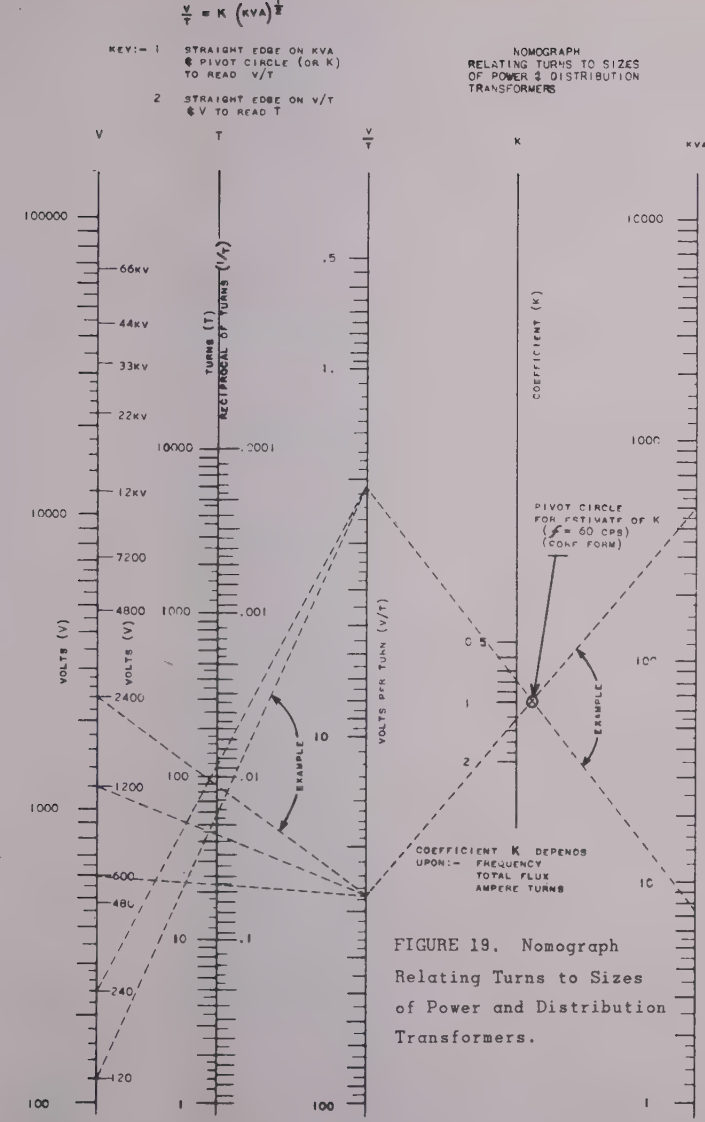


FIGURE 19. Nomograph Relating Turns to Sizes of Power and Distribution Transformers.

Transformers Having Faults

The TTR Set will be very useful as a first means of investigating the nature of faults on transformers which have failed in service. Various kinds of faults will affect turn ratio measurements in several ways among which are the following:

(a) Direct change of ratio:

When a portion of a winding is shorted out and the turns burned open the ratio will be raised or lowered according to whether it is the high-side or the low-side which is affected. Such faults usually involve relatively few turns and the change of ratio is very small (See Page 53). By comparing the ratios of individual sections as far as possible according to the taps accessible, one may determine which section (sections) is affected.

A similar effect occurs when the transformer is set on the wrong tap by incorrect manual operation or because of maladjustment of tap-changing gear.

Faults of this nature do not introduce losses in single-phase installations and therefore may not be indicated by temperature rise. Such a fault will cause unequal division of load in parallel operation or unbalance in polyphase operation. It is possible for such a condition in one transformer to cause temperature rise in another transformer, which has on occasion led to removing a good transformer from service while the one that was off-ratio was left in. Hence ratio tests in the field are necessary for investigation of unbalanced operation in banks of transformers.

(b) Burden:

Burden as used in this manual refers to any current other than exciting current in the transformer windings during a ratio test. Any sort of load is a burden, but for the purpose of ratio tests even a voltmeter may be excessive burden. Burden may be distinguished by the mechanical torque developed at the generator crank in order to produce the power component of the

generator output. Thus the operator is made aware of the presence of burden without being required to make a visual check of the instrument panel for this purpose.

Some transformer faults are interrupted by relay operation before burning clear, which may leave a section of the winding short-circuited thru some resistance. Tests made before placing the transformer in service may reveal a short-circuit that would produce a failure if the transformer were to be energized. Such faults produce noticeable burden on the TTR Set, but the power is not available to cause destruction. The ratio at which balance is obtained under burden will be in error by an amount which depends upon the power dissipated as well as upon the number of turns involved.

Strictly, the core losses of the transformer are burden. Since core losses are relatively small and can not be eliminated, they are included in the consideration of accuracy in Section III, but under unusual conditions of core-losses, saturation, or tank-losses the burden will be apparent. Whether or not such a condition is normal for the transformer under test depends upon its characteristics.

It is usually desirable to determine which winding is faulted. Occasionally the burden can be removed by opening one or more accessible connections in which case its location will be apparent. More usually the burden will be apparent on every possible test connection. One technique which has been effective is to short circuit each accessible section of the windings individually in succession while the transformer is excited by the TTR Set. By short circuiting a good winding the ratio is degraded further and the galvanometer of the TTR Set is deflected. When the short circuit is applied to the faulted winding, however, the change of ratio will not occur or will be of magnitude not consistent with that of other windings. Hence the location of the fault is revealed.

Sometimes these techniques will make it possible to order fabrication of replacement coils before the

transformer is dismantled so that the new coils may be on the way even while the transformer is being moved from its operating site to the shop.

(c) Continuity:

Sometimes a fault will be of such a nature that continuity is established between windings or to ground. The TTR Set is both adequate and convenient for checking continuity in addition to its other uses. To make a continuity test the H-lead clips are the test leads and the reference transformer is excited by closing the screws on the anvils of the clamps. The ratio dials should be adjusted to produce a reasonable voltage, such as 0.1 ratio dial setting, avoiding high settings. When the transformer under test is already connected to the exciting leads a potential will be induced in the winding under test and the ratio dials should be set slightly above or below the transformer ratio. It is obvious that continuity is essential to making the ratio test. The galvanometer will not be deflected when the secondary circuit is open. It is desirable, therefore, to be sure of continuity on every test by observing the galvanometer deflection above and below null, thus avoiding the possibility of mistaking an "open" circuit for a null balance.

In checking continuity between circuits the applied potential is the difference between the induced potentials of the TTR reference transformer and the transformer under test. Considering the magnitude of this potential and the impedances of the transformers, such a check is obviously not an insulation test and should not be expected to reveal intermittent or high resistance faults.

Coils

In the transformer shop it may be desirable to check the turn count of coils before the transformer is stacked. Extension of the principle of the ratio test to counting turns of coils is accomplished by establishing a virtual transformer. In general the coil is placed on a separable

core and excitation is applied to a suitable winding of the test coil or to a separate coil provided for the purpose.

The magnetic structure and the exciting coil must be so arranged that they act together as a transformer, not simply as a coil with iron thru it. In other words, the conditions for rational excitation as given at the beginning of Section IV apply here also.

Repetitive tests on a production coil may be accomplished by designing a separable core to suit the coil. If, however, one wishes to count turns in single-winding coils of a variety of sizes, it is better to start with an available core structure of such dimensions that a reasonable range of coil sizes may be accomodated. A special coil is then wound to excite the core. In either case the accessory apparatus is adapted to the special requirements of the job at hand.

It is convenient to excite by means of a coil having 100 turns so that arithmetic will be minimized. The exciting coil should be distributed fully over the core structure with special emphasis on placing adequate ampere-turns directly over the joints of the core. A single layer coil of wire-size chosen to fill all available space is desirable. Both resistance and exciting current should be as low as practical. A tube of fish paper or fuller board will protect the exciting winding and guide the yoke into place, but the magnetic joint should be designed so that it may be kept clean. Excessive air-gap will cause high exciting current and magnetic leakage errors. By placing the exciting coil over the joint as suggested, the leakage is reduced. If desired a multiple/series connection may be provided on the exciting coil but all the turns should be active.

Several stock sizes of "C-C" cores, available from the manufacturers of grain-oriented wound-strip types of magnetic cores, are especially suitable for this purpose.

A few simple observations will serve to indicate whether or not a virtual transformer has been made in this way. It is to be expected that the coil to be counted

will not be properly coupled magnetically if placed on the yoke instead of directly around the exciting turns, but, variations in ratio with position of the test-coil in the window should not occur if the exciting ampere-turns are properly distributed. The effectiveness of the joint may be checked by placing a piece of thin tissue paper or brass shim-stock in the joint, and observing the change of ratio in a test coil. If good distribution of exciting ampere-turns has been achieved it will be possible to open the gap slightly without change of ratio but a large change of exciting current will occur. If the core does not hum when excited the joint is probably clean and properly aligned.

It has thus far been evident that a user in need of an accessory coil and core prefers to make it from parts similar to those normally used with the coil to be tested.

Specialty Transformers

Many types of transformers other than power and distribution transformers may be tested by means of the TTR Set. Whether or not the ratio of a particular transformer may be tested successfully depends upon two considerations, (1) the ultimate purpose of the measurement, and (2) the degree of rationality of excitation under test conditions. The former determines the degree of precision and accuracy which will be useful and the latter determines what may be obtained.

Obviously applications such as identifying the individual terminals and their polarities or separating a mixed lot of radio-type plate transformers does not require a high order of accuracy, but checking a transformer ratio against specifications would require that the measurement be highly accurate. Since evaluating the purpose of the measurement does not depend upon characteristics of the instrument, this important aspect will not be discussed further.

The criteria for rational excitation have been discussed at the beginning of Section IV and apply here as

well. No general statement can be made regarding types which may be tested, but some guidance is given below.

Large numbers of small transformers having 115 volt primary windings with many combinations of high and low voltages on the secondaries are used for communication, signaling, and power-supply purposes as accessories to electrical equipment. In such transformers the copper size may be very small, the exciting component may be as much or more than the load component of full load current, and the design may be influenced by economy requirements. Excitation for ratio tests should be applied to a winding capable of carrying normal exciting ampere-turns, which will often be the primary winding and no other. In some cases applying 8 volts to the low voltage winding may saturate the core. Generally, therefore, small transformers intended for use with 115 volt input should be excited on the 115 volt winding for (TTR) ratio tests.

A rough check of the effectiveness of the ratio test on some small transformers can be made by comparing several ratios when several independent windings are available to be excited successively. If the ratio measurements are mutually consistent when exciting ampere-turns are applied in different physical locations (not various combinations of the same windings) there is reasonable assurance that all such modes of excitation are rational. If on the other hand one mode of excitation does not give results which are consistent with results from another mode of excitation, then one or both modes of excitation is subject to errors which are inherent in the dimensions and arrangement of the windings and the core structure.

NOTES

Section V

MAINTENANCE

The TTR Set is sturdily constructed to withstand the requirements of field use. Aside from good housekeeping practices no special attention is required. Factory inspection including lubrication of the generator is recommended at intervals of approximately 10 years.

Leads

The TTR Set is equipped with four leads (Fig. 4) permanently attached to the instrument as follows:

X1-S1) X2-S2) Two 2-conductor leads comprising a #18 AWG supply lead (S1, S2) cabled with a #9 AWG exciting lead (X1, X2) with a C-clamp for connection to the excited winding of the transformer under test. The resistance of the X1 or the X2 lead is 0.008 ohms. The resistance of the S1 or S2 lead is not critical but should not exceed 0.1 ohm in order to avoid excessive potential drop. It is recommended that the resistance of the X1-X2 circuit be measured periodically to detect strand failure. The nominal resistance of the excitation circuit of the TTR Set from clamp anvils thru the leads and exciting winding of the reference transformer at 25C is 0.045 ohms. In measuring lead resistance the S circuit should be insulated from the X circuit to avoid shunting by the supply circuit. The X lead is connected to the anvil and insulated from the clamp frame. The S lead is connected thru the frame to the clamp screw.

H1) Two single conductor #16 AWG leads with insulated copper clips.
H2) The resistance of the H leads is not critical.

The outer jackets of the leads are oil-resistant Neoprene.

Replacement sets of leads are available as follows:

Part No. 3-2798 lead assembly including 4 cables, boot, and "C" clamps

Part No. 3-2788 lead assembly including 4 cables with terminal lugs and boot (less "C" clamps).

In special applications leads may be supplied by the user subject to the requirements for maximum resistance.

Strand failure in the leads may be postponed by reasonable care in handling the leads. Since the leads are attached to the TTR Set they should be coiled from the instrument end with the clamps free to turn as necessary to avoid kinks in the cables. Coiling with the lay (clockwise) is preferred.

Decade Switches

The dial switches have self-wiping, silver contacts and should require no maintenance. A minimum application of petrolatum ("Vaseline") may be used should lubrication appear to be necessary.

Fourth Dial

The voltage divider element on the fourth dial is a circular slide wire resistor. Such resistance elements should be burnished after extended idleness by sweeping the rotor thru several revolutions. A minimum application of petrolatum ("Vaseline") may be used should lubrication appear to be necessary.

Restraining Strap for Cover

The restraining strap supports the cover when open and may be unbuttoned to permit removal of the cover. Replacement strap is available as follows:

Part No. 2-2759 Restraining Strap for Cover

Carrying Strap

The carrying strap of black strap leather may be replaced by removing the dial-knobs and the panel. Remove old carrying strap by taking off retainer rings. Insert studs of new strap into bushings so that the buckle of the strap is at the lead-compartment end of the instrument. The "Truarc" retainer rings should be sprung in place with special pliers but may be installed by spreading the points and carefully slipping the rings over the ends of the studs. Care should be taken to avoid overstressing the rings. They should snap snugly into the grooves in the studs.

Replacement sets of carrying straps are available as follows:

Part No. 2-7010 Strap assembly with 4 retainer rings. (Two rings required, two spares)

Panel Instruments

The glass fronts of the panel instruments should be protected by careful handling of the heavy clamps on the leads. Replacement of cover glasses should be undertaken only by persons qualified to repair instruments, since minute particles of broken glass or dust may enter the instrument when the movement is thus exposed. The instruments, made by Weston Electrical Instrument Corp. especially for the TTR Set, may be replaced from our stock as follows:

Part No. 3-2790	Ammeter for TTR Set
Part No. 3-2791	Voltmeter for TTR Set
Part No. 3-2792	Galvanometer for TTR Set
Part No. 2-7001-1	Cover Glass only
Part No. 2-7001-2	Retainer ring
Part No. 2-7001-3	Zero Adjusting Screw

Generator

The factory adjustment of the synchronous commutator on the generator shaft is made by means of special equipment and techniques which can not be readily duplicated in the user's shop. Hence, take care to avoid disturbing the adjustment if, for any reason, the TTR Set is opened.

Service and Repair

The foregoing information is given to expedite repairs by those users who have facilities to handle such work. Even where such facilities are available it is preferable to have repairs made at the factory. Repair facilities are maintained at our Philadelphia factory to render prompt and effective service on all Biddle instruments. Write or wire for shipping instructions, stating the serial number of the instrument.

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